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TITLE AN OVERVIEW OF AN EXPERIMENTAL PROGRAM FOR TESTING LARGE REINFORCED CONCRETE SHEAR WALLS

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AN OVERVIEW OF AN EXPERIMENTAL PROGRAM FOR TESTING LARGE REINFORCED CONCRETE SHEAR WALLS

by

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INTRODUCTION

The Seismic Category I Structures Program is being carried out at the Los Alamos National Laboratory under sponsorship of the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research. In the class of structure being investigated, the primary lateral load-resisting structural element is the reinforced concrete shear wall. Previous results from microconcrete models, (Endebrock et al, 1985, Dove et al, 1987, and Bennett et al, 1987a), indicated that these structures responded to seismic excitations with initial frequencies that were reduced by factors of 2 or more over those calculated based on an uncracked cross-section strength-of-materials approach. Furthermore, though the structures themselves were shown to have sufficient reserve margins, the equipment and piping are designed to response spectra that are based on uncracked cross-sectional member properties, and these spectra may not be inappropriate for actual building responses.

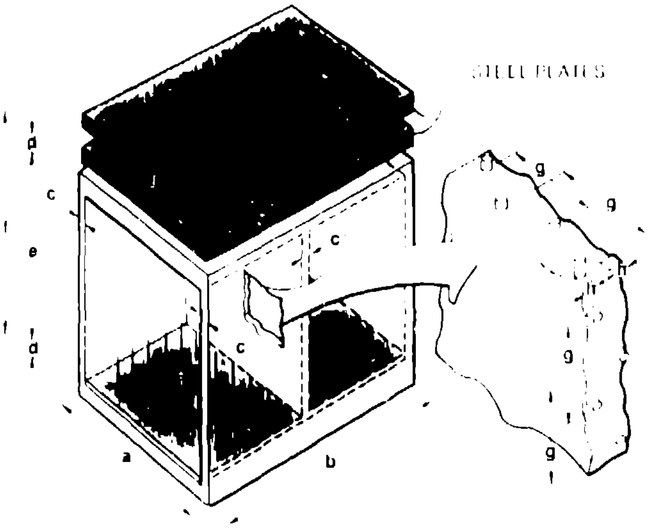
The current phase of the program is aimed at verification of these conclusions using conventional concrete structures to demonstrate that previous microconcrete results can be scaled to prototype structures. A new configuration of a shear wall structure was designed and tested to investigate the analytical-experimental differences observed during the previous model testing. Shear wall height-to-length aspect ratios were to vary from 1 to 0.25. Percentage steel ratios were to vary from 0.25% to 0.6% by area, in both horizontal and vertical directions. The test structures are shown in Fig. 1. TRG 1 and 2 were constructed with microconcrete. TRG 3, 4, 5, and 6 were constructed with conventional (19 mm aggregate) concrete.

STATIC TESTING

The static testings of TRG-1, 2, and 3 are discussed in Bennett et al, 1987b, and 1988, respectively. These tests were monotonic in nature and were aimed at measuring the initial stiffness of the structures without introducing significant damage to the structure. TRG 4, 5, and 6, were tested in a quasistatic, cyclic manner. A typical test setup is shown in Fig. 2 and a typical load sequence is shown in Fig. 3 for the TRG 4 structure. Instrumentation was provided to measure total deformation, shear deformation, bending deformation, torsional motion, and strain in the rebar.

DYNAMIC TESTING

Experimental modal analyses were performed on all the TRG structures before other static or dynamic tests. In this context, experimental modal analysis refers to the methods whereby a measured excitation (random, sine, or impact



STRUCTURE	a	b		d	e	f	g	h	ADDED WEIGHT (kN)	REBAR diam (mm)
TRG 1 2	[illegible]	[illegible]	[illegible]	[illegible]	58	68	0.6*	[illegible]*	[illegible]	[illegible]
TRG 3 5	230	300	10	20	230	270	11*	3.8*	[illegible]	[illegible]
TRG 4	230	300	15	20	230	270	37	2.5	[illegible]	10
TRG 6	230	300	15	20	61	101	18	2.5	[illegible]	10

* ONE LAYER OF REINFORCEMENT DOWN THE CENTER OF THE WALL IN BOTH THE HORIZONTAL AND VERTICAL DIRECTION

Fig. 1. The TRG structures.

force) is applied to a structure and its response (acceleration, velocity, displacement, etc) is measured at a discrete number of locations that are representative of the structure's motion. Both the excitation and the response time histories are transformed into the frequency domain so that modal parameters (frequencies, modes, damping) can be determined by curve fitting the measured frequency domain data to a Laplace domain representation of the equations of motion. These experimental modal analysis techniques, which have rarely been applied to large reinforced concrete structures, are described by Ewins, 1985, and Farrar, 1988. Fig. 4 shows the TRG-4 structure resting on air bearings to simulate free-boundary conditions with the shaker attached.

TRG 1 and 3 were subjected to repeated simulated seismic base excitations on a shake table. From these seismic tests, the dynamic properties of the shear walls could be determined from the measured acceleration responses and degradation of these properties with excitation level was monitored. The seismic signal that was used in all the testing was a time scaled version of the north south component of the 1940 El Centro earthquake.

DISCUSSION OF RESULTS

Static Monotonic Testing of TRG-1 and 3

During the low stress level monotonic, static tests on TRG 1 and 3, both structures exhibited stiffnesses that were 70% 80% of the values that a strength of materials analysis using measured material properties, herein referred to as theoretical stiffness, would predict. When the differences in the structure's modulus of elasticity were accounted for, scalability of the stiffness from the microconcrete model (TRG 1) to the conventional concrete structure (TRG 3) was demonstrated.

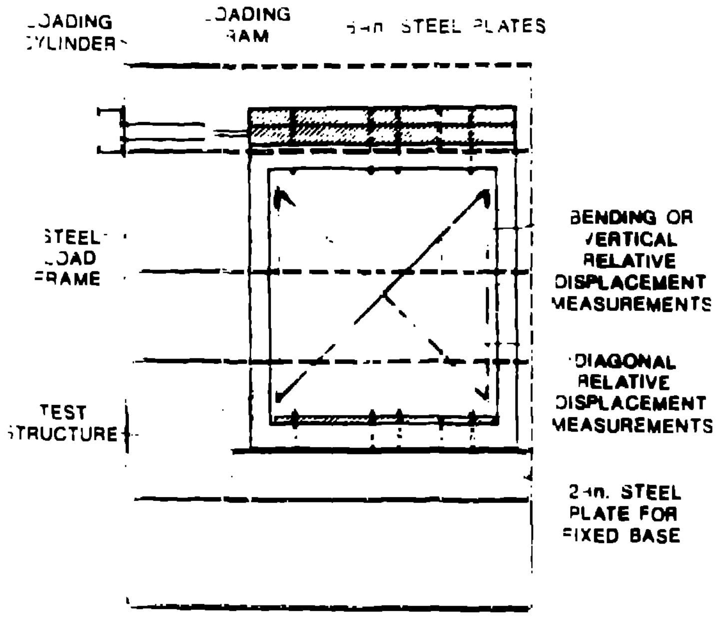


Fig. 2. Static test setup for TRG-4.

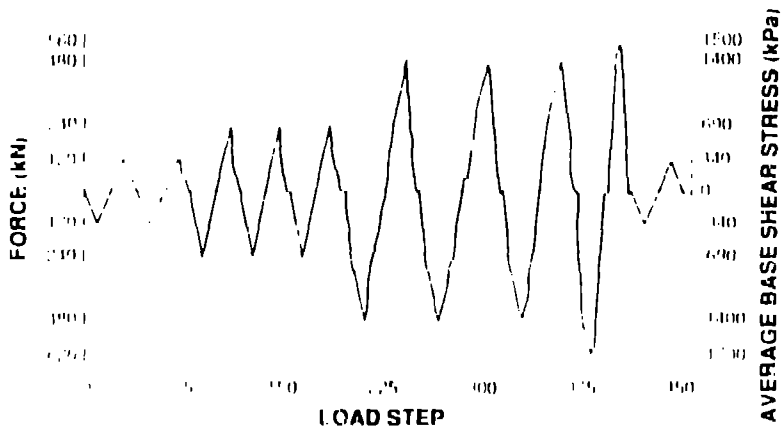


Fig. 3. Static load history for TRG 4.

Static Cyclic Testing of TRG-4, -5, and -6

Before cracking, all three structures exhibited stiffness values that were in good agreement with theory. The individual components of stiffness (shear and bending) were also shown to agree with theory. No degradation in stiffness was observed on TRG 6 when it was subjected to repeated load cycles below its cracking strength.

After cracking, the stiffness was found to be a function of load level, past load history, and the amount of reinforcement. First cracking loads were slightly less than those predicted by ACI Committee 349, 1983, and the ultimate strength of the walls exceeded the values given in ACI Committee 349, 1983.

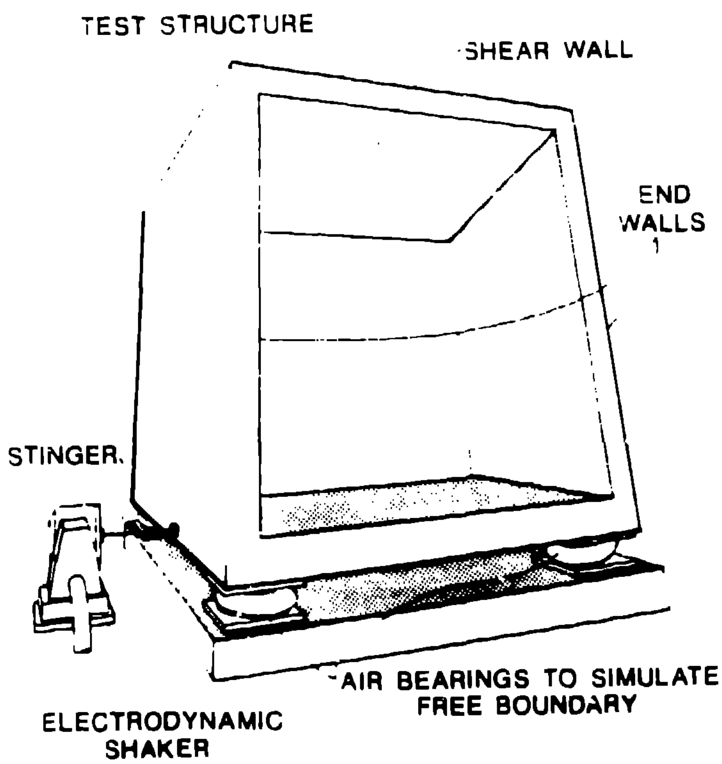


Fig. 4. Experimental modal analysis testing of TRG-4.

During cycles that exhibited linear response, hysteretic energy losses were measured and equivalent viscous damping ratios were determined from these energy losses. These ratios were in good agreement with the values reported by Stevenson, 1980, the United States Nuclear Regulatory Commission, 1973, and Shiga et al, 1973, but were less than the ratios measured during simulated seismic testing on the shake table.

Experimental Modal Analysis Results

The experimental modal analyses gave excellent results (resonant frequencies, mode shapes) when compared with finite element modal analyses. Modal damping ratios were significantly less than those determined from the hysteretic energy losses or from frequency response functions measured during simulated seismic testing. This difference demonstrates the stress-level dependence of damping in reinforced concrete structures, as has been previously noted by Stevenson, 1980.

Again, scalability was demonstrated between the 1/4-scale, microconcrete TRG-1 model and the conventional concrete TRG-1 and -5 prototypes in terms of resonant frequencies and mode shapes.

Simulated Seismic Test Results

During the simulated seismic testing, resonant frequencies measured on both TRG-1 and TRG-4 were significantly below theoretical values. This suggests that the actual stiffnesses were well below those that industry would currently use in the design process. Damping was measured at 7% to 10% of critical during these tests. As the amplitude of the seismic excitation was increased, the fundamental frequency decreased and the modal damping ratio increased. Scalability of the seismic response was difficult to establish because an accurate reproduction of the input signal was difficult to obtain during the testing of TRG-3 because of the structure's size.

SUMMARY

The TRG structures have generated many experimental data concerning the structural properties of the shear walls. Both the experimental modal analysis results and the static testing results showed good agreement with theory. During the quasistatic testing, TRG-4, -5, and -6 tracked theory almost exactly, up to the first cracking load, and the individual components of stiffness were also shown to agree almost exactly with theory. Although TRG-1 and TRG-3 did not show similar quality results during the static tests, the stiffness values were within reason and errors were probably caused by difficulties in constructing sound, thin-walled, reinforced concrete structures or by difficulties in handling.

The difference in effective stress levels at which the reduced stiffness occurs is still a matter of concern. Previous results on microconcrete models showed that the reductions in stiffness occur at similar stress levels in both static and seismic testing. TRG-3 (a seismic test) showed a 75% stiffness reduction during a 0.73-g peak acceleration earthquake signal. This excitation level corresponds to an equivalent static load of 144 kN producing a maximum tensile stress of 630 kPa, which is well below the levels required to produce cracking. However, TRG-5, a quasistatic test, had good analytical-experiment agreement. There appears to be a significant difference between the stiffness properties of these structures identified during static and modal testing and the stiffness properties identified during seismic testing.

Possible causes for the reductions in stiffness are currently being investigated: (1) Were the structures damaged before the seismic testing either by handling, or, in the case of smaller structures, shrinkage cracks? (2) Are there dynamic effects that cause the discrepancies? (3) Have the boundary conditions been properly accounted for in all tests and analyses? Based on the analytical studies of TRG-3, base connection effects can be discounted as a cause of the apparent reduced stiffness. Based on the outcome of the TRG-3 seismic testing, the reduced stiffness cannot be attributed to microconcrete effects.

The seismic testing results have confirmed previous findings related to the equivalent viscous damping. That is, the equivalent viscous damping appears to be 7% - 10% of critical during typical seismic excitations. Damping ratios evaluated from hysteretic energy losses showed slightly smaller values.

In summary, the most likely cause of the reduced stiffness that has been measured in this program is concrete cracking. The source of this cracking has probably been (in our tests) a combination of several causes that include handling and transportation loadings, aging (curing), shrinkage, and other time effects, and the construction imperfections and material variability that exist in all fabricated structures. However, it is felt that the same cracking effects exist in real nuclear plant structures because of many of the same reasons (handling and transportation loadings can be replaced by "differential settlement" in actual plant structures). Therefore, the current method of treating these structures using an uncracked cross section for determining the structural element parameters and resulting floor response spectra should be re-examined and more realistic guidelines should be established to cover the effects. Investigators at Los Alamos are working with professional society committees in this re-examination.

Scalability of the structural response of microconcrete models to conventional concrete prototype was demonstrated during static testing and experimental modal analyses. Additional tests would be necessary to demonstrate this scalability during seismic excitations. Also, additional tests of carefully handled structures should be performed to verify that undamaged structures will behave dynamically, as theory would predict.

The NRC is sponsoring a complementary research program to assess the effects of reduced structural stiffness on plant seismic design (building accelerations and displacements, and floor response spectra) and seismic risk. From this research, the NRC will be able to evaluate safety concerns associated with the reduced stiffness in concrete shear walls.

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